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Accumulation and Crop Uptake of Soil Mineral Nitrogen as Influenced by Tillage, Cover Crops, and Nitrogen Fertilization

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ABSTRACT

Management practices may influence soil N levels due to crop uptake and leaching. We evaluated the effects of three tillage practices [no-till (NT), strip till (ST), and chisel till (CT)], four cover crops [hairy vetch (*Vicia villosa* Roth), rye (*Secale cereale* L.), vetch + rye biculture, and winter weeds or no cover crop], and three N fertilization rates (0, 60–65, and 120–130 kg N ha^{-1}) on NH_4–N and NO_3–N contents in Dothan sandy loam (fine-loamy, kaolinitic, thermic, Plinthic Paleudults), and N uptake by cotton (*Gossypium hirsutum* L.) and sorghum [*Sorghum bicolor* (L.) Moench] from 2000 to 2002 in central Georgia. Nitrogen content was higher in vetch and vetch + rye than in rye and weeds. Soil NH_4–N content at 0 to 30 cm was higher at harvest than at planting, and higher in NT or vetch with 120 to 130 kg N ha^{-1} than with other treatments. The NO_3–N content at 0 to 120 cm varied with date of sampling and was higher with vetch than with rye and weeds. The NO_3–N content at 0 to 10 cm was higher in CT with vetch than in NT and ST with rye or weeds. From November 2000 to April 2001 and from November 2001 to April 2002, N loss from crop residue and soil at 0 to 120 cm was higher with vetch than with other cover crops. Nitrogen removed by cotton lint was higher with rye than with other cover crops in 2000 and higher with 0 and 60 than with 120 kg N ha^{-1} in 2002, but N removed by sorghum grain and cotton and sorghum biomass were higher with vetch than with rye, and higher with 120 to 130 than with 0 kg N ha^{-1}. Because of higher N supply, vetch increased soil mineral N and cotton and sorghum N uptake compared with rye, but also increased the potential for N leaching. The potential for N leaching can be reduced and crop N uptake can be optimized by mixing vetch with rye.

It is well known that agricultural practices, such as intensive tillage and excessive N fertilization, can increase N leaching in groundwater, which is a major environmental concern (Liang and McKenzie, 1994; Yadav, 1997; Al-Kaisi and Licht, 2004). Tillage accelerates mineralization of crop residue and soil organic N (Sainju and Singh, 2001; Dinnes et al., 2002) and increases accumulation of NO_3–N in the soil profile (Yadav, 1997; Halvorson et al., 2001; Al-Kaisi and Licht, 2004). Deep accumulation of NO_3–N in the soil profile increases the potential for N leaching to shallow water tables (Keeney and Follett, 1991). Similarly, N fertilization rates that exceed crop requirement can increase NO_3–N accumulation in the soil profile and N leaching (Hallberg, 1989; Liang and McKenzie, 1994; Yadav, 1997). Nitrogen recovery by crops during their growth seldom exceeds 70% of applied N and averages 50% or less (Hallberg, 1989; Bergstrom and Kirchmann, 2004). Therefore, improved soil and crop management practices that optimize soil mineral N content and crop N uptake are needed to reduce NO_3–N accumulation in the soil profile and the potential for N leaching.

Winter cover crops have been increasingly used to scavenge residual N in the soil after autumn crop harvest to reduce N leaching and increase N supply for succeeding summer crops. As a result, N fertilization rate can be either reduced or eliminated to reduce the cost of N fertilization. The effectiveness of cover crops in reducing N leaching and increasing N supply depends on the species. Studies have shown that nonlegume cover crops, such as rye (*Secale cereale* L.) and annual ryegrass (*Lolium multiflorum* L.), were more effective in reducing residual soil N (Kuo et al., 1997; Vyn et al., 1999) and N leaching (McCracken et al., 1994; Bergstrom and Kirchmann, 2004) than legumes, such as hairy vetch (*Vicia villosa* Roth), or noncover cropped soil. Sainju and Singh (1997), in a review of literature, concluded that nonlegumes reduced N leaching by 29 to 94% compared with 6 to 48% for legumes. The effectiveness of cover crops in reducing soil N accumulation depends on their ability to establish rapidly in the fall and to extend their root system (Kuo et al., 1997; Sainju et al., 1998). Nonlegumes, such as rye and annual ryegrass, have extensive root systems and remove more N from the soil than legumes or noncover cropped soil (Kuo et al., 1997; Sainju et al., 1998). In contrast, legumes increased soil mineral N content and crop N uptake as compared with nonlegumes (Vyn et al., 1999; Bergstrom and Kirchmann, 2004). A mixture of legume and nonlegume cover crops could be ideal to sustain both soil mineral N content and crop N uptake and reduce the potential for N leaching.

Tillage may interact with cover crop and N fertilization in soil N mineralization and mineral N content, thereby influencing crop N uptake and N leaching. Varco et al. (1987) found that hairy vetch residue released N more rapidly when incorporated into the soil with tillage than when left at the soil surface with no-tillage. Similarly, Sainju and Singh (2001) reported that soil inorganic N content at the 0- to 30-cm depth was higher in hairy vetch with chisel and moldboard till than in noncover cropped soil with NT. As a result, N uptake by sorghum was greater in red clover (*Trifolium pratense* L.) and hairy vetch with reduced till than in noncover cropped soil with NT (Sweeney and Moyer, 2004). Greater soil N accumulation with increasing N fertilization rate (Liang and McKenzie, 1994; Sainju et al., 1999) poses a higher risk of N leaching in nontilled than in

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Abbreviations: CT, chisel till; NT, no-till; and ST, strip till.

tilled soil due to presence of large macropores (Tollner et al., 1984; Sainju et al., 1999). Nitrogen content in the soil, N leaching, and crop N uptake from legume cover crops may be lower, similar to, or greater than those from N fertilization. Sainju et al. (1999) observed that soil mineral N content and tomato (*Lycopersicum esculentum* Mill.) N uptake were similar between hairy vetch and applied N fertilization rates between 90 and 180 kg N ha^{-1}. Bergstrom and Kirchmann (2004) reported that N removed by barley (*Hordeum vulgare* L.) was greater with a N fertilization rate of 80 kg N ha^{-1} than with red clover, but N leaching with red clover was higher.

Continuous use of improved soil and crop management practices, such as conservation tillage and cover cropping, to enhance soil quality and productivity can also influence soil mineral N and crop N uptake. Although crop N uptake may or may not be influenced by tillage practices (Al-Kaisi and Licht, 2004), long-term cover cropping may increase N leaching compared with no-cover cropping due to continuous N mineralization from cover crop residues (Hansen et al., 2000), even though cover crops reduce N leaching over the short-term (Bergstrom and Jokela, 2001). Information on the long-term influence of management practices on soil N accumulation is limited. Similarly, little is known about the use of legume and nonlegume cover crop mixture on soil mineral N and crop N uptake. Cover crop mixtures can enhance soil productivity by building active organic matter pools and increasing N mineralization due to their large biomass production (Mutch and Martin, 1998). We hypothesized that a mixture of legume and nonlegume cover crops and 60 to 65 kg N ha^{-1} in conservation tillage could optimize cotton and sorghum N uptake and reduce soil profile N accumulation compared with legume and nonlegume cover crops and 120 to 130 kg N ha^{-1} in conventional tillage. Our objectives were to: (i) examine the amount of N returned to the soil from cover crop residues; and (ii) determine the effects of tillage, cover crops, and N fertilization rates on soil NH_4–N and NO_3–N contents at the 0- to 120-cm depth and cotton and sorghum N uptake from 2000 to 2002 in the southeastern USA.

MATERIALS AND METHODS

Experimental Site and Treatments

The experiment was conducted at the Agricultural Research Station farm, Fort Valley State University, Fort Valley, Georgia, USA. The soil is a Dothan sandy loam (fine-loamy, kaolinitic, thermic, Plinthic Kandiudults), with pH of 6.5 to 6.7 and sand content of 650 g kg^{-1}, silt 250 g kg^{-1}, and clay 100 g kg^{-1} soil at the 0- to 30-cm depth. The clay content increased to 350 g kg^{-1} below 30 cm. The soil sampled in October 1999 before cover crop planting had organic C of 8.8 g kg^{-1} and organic N of 620 mg kg^{-1} at 0 to 30 cm. Previous crops were tomato from 1995 to 1997 and silage corn (*Zea mays* L.) from 1998 to 1999. Temperature and rainfall data were collected from a weather station, 20 m from the experimental site.

Treatments consisted of three tillage practices (NT, ST, and CT), four cover crops [legume (hairy vetch), nonlegume (rye), legume + nonlegume (hairy vetch + rye) biculture, and winter weeds or no cover crop], and three N fertilization rates (0, 60–65, and 120–130 kg N ha^{-1}). In ST (or reduced till), cropping rows were subsoiled to a depth of 35 cm in a narrow strip of 30 cm, thereby leaving 60 cm between rows undisturbed. The surface tilled zone is leveled by coulters behind the subsoiler. The CT consisted of plowing the soil with disc harrow and chisel plow to a depth of 15 to 20 cm, followed by leveling with a S-tine harrow. The NT soil was left undisturbed, except for planting cover crops, cotton, and sorghum. The 120 kg N ha^{-1} is the recommended rate of N fertilization for cotton and 130 kg N ha^{-1} for sorghum in central Georgia (University of Georgia, 1999, 2001). Treatments were laid out in a split plot arrangement in randomized complete blocks, with tillage as the main plot factor, cover crop as the split-plot factor, and N fertilization rate as the split-split-plot factor. Each treatment had three replications. The split-split plot size was 7.2 by 7.2 m.

Cover Crop Management

Cover crops were planted October to November, 1999 to 2001, in the same plot every year to examine their long-term influence on soil quality and productivity. Hairy vetch seeds were drilled at 28 kg ha^{-1} after inoculating with *Rhizobium leguminosarum* (bv. viceae) and rye at 80 kg ha^{-1}, using a row spacing of 15 cm. In the vetch + rye biculture, hairy vetch was drilled at 19 kg ha^{-1} (68% of monoculture), followed by rye at 40 kg ha^{-1} (50% of monoculture) in between vetch rows. The rates of hairy vetch and rye in the biculture were based on the recommendation of Clark et al. (1994). Cover crops were drilled in plots without any tillage because previous studies have shown that cover crop aboveground biomass yields and N accumulation were not significantly influenced by tillage practices (Sainju et al., 1999; Sainju and Singh, 2001). No fertilizers, herbicides, or insecticides were applied to cover crops.

In April, 2000 to 2002, cover crop biomass yield was determined by hand harvesting plant samples from two 1-m^2 areas randomly within each plot and weighed in the field. A subsample (≈100 g) was collected for determinations of dry matter yield and N concentration and the remainder of the plant sample was returned to the harvested area where it was spread uniformly by hand. In plots without cover crop, winter weeds, dominated by henbit (*Lamium amplexicaule* L.) and cut-leaf evening primrose (*Oenolthera laciniate* Hill), were collected using the same procedure. Plant samples were oven-dried at 60°C for 3 d, weighed, and ground to pass a 1-mm screen. After sampling, cover crops and weeds were mowed with a rotary mower to prevent residues from dragging while plowing and seeding. In NT and ST, cover crops were killed by spraying 3.36 kg a.i. ha^{-1} of glyphosate [*N*-(phosphonomethyl) glycine]. In CT, cover crops were killed by disc harrowing and chisel plowing. Residues were allowed to decompose in the soil for 2 wk before cotton and sorghum planting.

Cotton and Sorghum Management

At the time of planting cotton and sorghum in May, 2000 to 2002, P {as triple superphosphate [$Ca(H_2PO_4)_2$]} fertilizer at 36 kg P ha^{-1} for cotton, 40 kg P ha^{-1} for sorghum, K [as muriate of potash (KCl)] fertilizer at 75 kg K ha^{-1} for cotton, and 80 kg K ha^{-1} for sorghum, were broadcast in all plots based on the soil test and crop requirement. At the same time, B [as boric acid (H_3BO_3)] fertilizer at 0.23 kg ha^{-1} for cotton was also broadcast. Nitrogen fertilizer as NH_4NO_3 was applied at three rates (0, 60, 120 kg N ha^{-1}) for cotton in 2000 and 2002, half of which was broadcast at planting and other half broadcast 6 wk later. Similarly, NH_4NO_3 was applied at three rates (0, 65, 130 kg N ha^{-1}) for sorghum in 2001, two-thirds of which was broadcast at planting and other one-third broadcast

6 wk later. The fertilizers were left at the soil surface in NT, partly incorporated into the soil in ST, and completely incorporated in CT by plowing.

Following tillage, glyphosate-resistant cotton [cv. DP458BR (Delta Pine Land Co., Hartsville, SC)] at 8 kg ha^{-1} in 2000 and 2002 and sorghum [cv. 9212Y (Pioneer Hi-Bred Int., Hunstville, AL)] at 12 kg ha^{-1} in 2001 were planted in 8-row (each 7.2 m long) plots (0.9-m spacing) with a NT-equipped unit planter. Although the experiment was planned to plant continuous cotton from 2000 to 2002, sorghum was planted in 2001 to reduce the incidence of weeds, diseases, and pests. Cotton was sprayed three times with glyphosate at 3.36 kg a.i. ha^{-1} in 2000 and 2002 to control weeds immediately after planting and during cotton growth. For sorghum, atrazine [6-chloro-*N*-ethyl-*N′*-(1-methylethyl)-1,3,5-triazine-2,4-diamine] at 1.5 kg a.i. ha^{-1} and metolachlor [(2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl) acetamide] at 1.3 kg a.i. ha^{-1} were applied within a day after planting to control post-emergence of weeds. Aphids (*Aphis gossypii* Glover) in cotton were controlled by spraying endosulfan (6, 7, 8, 9, 10-10-hexachloro-1, 5, 5a, 6, 9, 9a-hexahydro-6, 9 methano-2, 4, 3 benzodioxathiepin-3-oxide) at 0.6 kg a.i. ha^{-1}. Cotton was also sprayed with the growth regulator, Pix (1, 1-dimethyl-piperdinium chloride), at 0.8 kg a.i. ha^{-1} at 8 wk after planting to control vegetative growth. Similarly, the defoliant, Cotton-quik [1-aminomethanamide dihydrogen tetraoxosulfate ethephon (2-chloroethyl) phosphoric acid], at 2.8 L ha^{-1} was applied to cotton a day after biomass collection and 2 to 3 wk before seed and lint harvest to defoliate leaves. Irrigation (totaling 75–100 mm every year using reel rain gun) was applied to cotton and sorghum immediately after planting and fertilization and during dry periods to prevent moisture stress.

In October to November, 2000 and 2002, aboveground cotton biomass samples containing stems, leaves, and lint (including seeds) were hand harvested from two 1.8 × 1.8-m^2 areas randomly in places next to yield rows a week before the determination of lint yield. After removing lint and seeds, biomass samples containing stems and leaves were weighed, chopped to 2.5-cm length, and mixed thoroughly, from which a representative subsample of 100 g was collected, oven-dried at 60°C for 3 d, and ground to 1 mm for N analysis. Lint yield was determined by hand harvesting lint containing seeds from two central rows (6.2 by 1.8 m^2), separating lint from seeds after ginning, and weighing them separately. Similarly, in November 2001, aboveground sorghum biomass samples containing stems and leaves (after removing grains) were collected from two 1.8- by 1.8-m^2 areas randomly in places next to yield rows, a week before the determination of grain yield. These were weighed, chopped to 2.5-cm length, and mixed thoroughly, from which a subsample of 100 g was oven-dried at 60°C for 3 d and ground to 1 mm for N analysis. Grain yield was determined by hand harvesting heads from two central rows (6.2 by 1.8 m^2), separating grains from heads, drying to 15% moisture content, and weighing. After collecting samples, cotton lint containing seeds and sorghum grains were removed from the remaining plants within the plot using a combine harvester and biomass residues containing stems and leaves were returned to the soil.

Soil Sample Collection and Analysis

Within 2 wk after returning cover crop, cotton, and sorghum residues to the soil, soil samples were collected from the 0- to 120-cm depth from each plot using a hydraulic probe (5 cm i.d.) attached to a tractor. Samples were collected from four holes, two in rows and two in between, from middle rows in each plot. The soil core was divided into 0- to 10-, 10- to 30-, 30- to 60-, 60- to 90-, and 90- to 120-cm segments to represent their respective depths from the soil surface. Samples from four cores were composited within a depth, air-dried, ground, and sieved to 2 mm. Samples were collected in April 2 wk after cover crop kill before N fertilization to cotton and sorghum and in November after cotton and sorghum harvest in each year from 2000 to 2002, except in 2000 when soil samples were collected in May instead of April from the 0- to 30-cm depth after N fertilization. Bulk density of soil at each depth and sampling date was determined by the diameter of the probe, soil depth, and mass of the oven-dried soil by drying 10 g soil subsamples at 105°C.

The NH_4–N and NO_3–N concentrations (g kg^{-1} soil) in the soil were determined by steam distillation after extracting the soil with 2 *M* KCl for 1 h (Mulvaney, 1996). Total N concentration in the soil (g kg^{-1} soil) and C and N concentrations (g C and N kg^{-1} plant dry weight) in cover crops and N concentration in cotton and sorghum biomass were determined by using dry combustion C and N analyzer (LECO Co., St. Joseph, MI). The NH_4–N, NO_3–N, and total N contents (kg ha^{-1}) at a particular depth were determined by multiplying their concentrations by bulk density (for that depth) and soil depth. Organic N content was calculated as the difference between total N and sum of NH_4–N and NO_3–N contents. Carbon and N contents (Mg ha^{-1}) in cover crop, cotton, and sorghum biomass were determined by multiplying dry matter weight by total C and N concentrations.

Data Analysis

Data for C and N contents in cover crops, cotton, and sorghum were analyzed using the split-split plot analysis in the MIXED procedure of SAS after testing for homogeneity of variance (Littell et al., 1996). Tillage, cover crop, N fertilization rate, and their interactions were considered fixed effects, and replication and tillage × cover crop × replication interaction were considered random effects. For soil NH_4–N, NO_3–N and organic N concentrations and contents, data were analyzed using the Analysis of Repeated Measures in the MIXED procedure after considering tillage, cover crop, N fertilization rate and their interactions in the split-plot arrangement as fixed effects as above and soil depth and date of soil sampling as repeated measure factors. Means were separated by using the least square means test when treatments and their interactions were significant. Statistical significance was evaluated at $P \leq 0.05$, unless otherwise stated.

RESULTS AND DISCUSSION

Cover Crop Biomass Yield and Nitrogen Content

Tillage and N fertilization to previous crops including cotton in 2000 and sorghum in 2001 did not significantly ($P \leq 0.05$) influence cover crop biomass yield, N content, and C/N ratio. It is not surprising to observe higher biomass yield in cover crops than in winter weeds (Table 1). Biomass yield, averaged across tillage and N fertilization rates, was higher in rye than in hairy vetch in 2000 and 2001 but was lower in 2002. In contrast, N content was higher in vetch than in rye in all years. Biomass yield and N content were similar to or higher in vetch + rye than in vetch and higher than in rye. Biomass yield and N content decreased from 2000 to 2002 in rye but were higher in 2000 and 2002 than in 2001 in vetch. Biomass yield and N content were higher in 2000 than in 2001 and 2002 in vetch + rye. The C/N ratio was higher in rye than in other cover crops due to lower N

Table 1. Biomass (stems + leaves) yield, N content, and C/N ratio of cover crops averaged across tillage and N fertilization rates from 2000 to 2002 in Fort Valley, GA.

Year	Cover crop†	Biomass yield	N content	C/N ratio
		Mg ha^{-1}	kg ha^{-1}	
2000	rye	6.07b‡	68c	29a
	vetch	5.10c	165b	12c
	vetch + rye	8.18a	310a	10c
	weeds	1.65d	25d	24b
2001	rye	3.81b	32b	57a
	vetch	2.44c	76a	12c
	vetch + rye	5.98a	84a	32b
	weeds	0.75d	15b	20c
2002	rye	2.28b	25b	40a
	vetch	5.16a	167a	10c
	vetch + rye	5.72a	186a	11c
	weeds	1.25c	23b	21b

† Cover crops are rye, cereal rye; vetch, hairy vetch; vetch + rye, hairy vetch and rye biculture; and weeds, winter weeds or no cover crop.
‡ Numbers followed by different letter within a column of a year are significantly different at $P \leq 0.05$ by the least square means test.

concentration, but the ratio was similar to or higher in vetch + rye than in vetch.

The higher N content in vetch than in rye was due to increased N concentration (32–36 g kg^{-1} in vetch vs. 8–15 g kg^{-1} in rye), although biomass yield was higher in rye than in vetch in 2000 and 2001 (Table 1). In vetch + rye, increased N content was attributed to both increased biomass yield and N concentration (14–38 g kg^{-1}) compared with rye. The reasons for decreased biomass yield and N content in rye from 2000 to 2002 were not known, since soil NO_3–N content with rye did not decline from May 2000 to April 2002, rather it increased in April 2002 (Table 2). A cold temperature in December 2000 compared with December 2001 and the 41-yr average (Table 3) could have decreased vetch biomass yield and N content in 2001 compared with 2000 and 2002 due to reduced growth. The vetch + rye biculture maintained almost constant biomass yield from 2000 to 2002 despite fluctuations in temperature and rainfall during these years (Table 3). It is expected that residues of vetch and vetch + rye, with their higher N content and lower C/N ratio, would mineralize rapidly in the soil, enrich soil mineral N, and sustain cotton and sorghum N uptake better than rye or winter weeds.

Table 2. Effects of cover crops and tillage on soil NO_3–N content at various soil depths averaged across N fertilization rates from May 2000 to November 2002 in Fort Valley, GA.

Soil depth	Treatment	2000 May	2000 Nov.	2001 Apr.	2001 Nov.	2002 Apr.	2002 Nov.
cm		kg NO_3–N ha^{-1}					
		Cover crop†					
0–10	rye	8.3	9.8	6.1	7.4	19.1	11.4
	vetch	15.4	11.2	6.1	9.3	27.6	13.8
	vetch + rye	10.8	10.5	5.7	9.0	27.3	12.0
	weeds	10.0	10.9	5.6	7.4	15.6	10.7
LSD (0.05) for comparison among columns and rows = 2.6							
0–120	rye	–‡	122.5	80.8	89.9	91.7	129.6
	vetch	–	133.6	105.9	110.5	123.1	148.6
	vetch + rye	–	128.2	82.3	89.3	104.3	132.2
	weeds	–	127.5	79.1	85.6	95.3	116.8
LSD (0.05) for comparison among columns and rows = 19.8							
		Tillage§					
10–30	NT	14.2	18.8	20.9	14.3	19.9	22.1
	ST	17.9	21.4	12.8	13.7	23.1	23.3
	CT	18.5	21.0	13.3	15.5	15.6	23.8
LSD (0.05) for comparison among columns and rows = 3.6							

† Cover crops are rye, cereal rye; vetch, hairy vetch; vetch + rye, hairy vetch and rye biculture; and weeds, winter weeds or no cover crop.
‡ Soil samples in May 2000 were collected only from the 0- to 30-cm depth. Therefore, data for soil NO_3–N content at the 0- to 120-cm depth was not available for this sampling date.
§ CT, chisel till; NT, no-till; and ST, strip till.

Table 3. Mean monthly air temperature and total monthly rainfall at the experimental site from 2000 to 2002 in Fort Valley, GA.

Month	2000	2001	2002	41-yr avg.
	Temperature, °C			
Jan.	8.0	7.0	9.6	8.4
Feb.	11.7	12.5	18.8	10.3
Mar.	13.3	11.9	14.5	14.1
Apr.	15.8	17.9	19.7	18.6
May	23.9	21.9	21.5	22.5
June	25.9	24.5	25.6	25.4
July	27.3	26.6	27.2	26.8
Aug.	26.6	26.5	26.6	26.5
Sept.	22.5	22.5	24.8	24.1
Oct.	18.4	17.0	19.8	18.3
Nov.	12.4	16.6	11.3	13.4
Dec.	4.3	11.9	7.3	9.6
	Rainfall, mm			
Jan.	93	47	49	143
Feb.	8	23	46	124
Mar.	111	179	70	119
Apr.	18	44	59	79
May	15	52	40	95
June	137	159	145	121
July	81	51	122	131
Aug.	82	39	88	90
Sept.	82	53	127	69
Oct.	18	2	98	62
Nov.	90	51	99	77
Dec.	48	28	123	123
Nov.–Apr.†	278	431	303	588
May–Oct.	505	356	620	645
Jan.–Dec.	780	721	1060	1215

† Includes total rainfall from November of the previous year to April of the following year.

Soil Ammonium Nitrogen

Variations in soil NH_4–N concentrations with depths at different sampling dates led to a significant ($P \leq 0.05$) soil depth × date of sampling interaction. The NH_4–N concentration, averaged across treatments, decreased from the 0- to 10-cm to the 30- to 60-cm layer, after which it either remained at the same level or increased (Fig. 1A). The NH_4–N concentration was higher in November 2000 and 2002 than in other sampling dates at all depths, except for the November 2001 sample at 0- to 10- and 90- to 120-cm layers. The NH_4–N concentration was lower in April 2002 than in other sampling dates. Because soil samples in May 2000 were not collected below the 30-cm depth, data for NH_4–N concentration at 30 to 120 cm for this sampling date were not available.

The decrease in NH_4–N concentration from the 0- to 10-cm to the 30- to 60-cm layer (Fig. 1A) was likely related to decrease in substrate availability with depth, since soil organic matter and root growth of cover crops, cotton, and sorghum also decreased with depth (Sainju et al., 2005a, 2005b). However, similar or increased levels of NH_4–N at the 60- to 120-cm layer indicate a slow mineralization at this depth. Since clay content in the soil profile increased below 30 cm, greater NH_4–N level

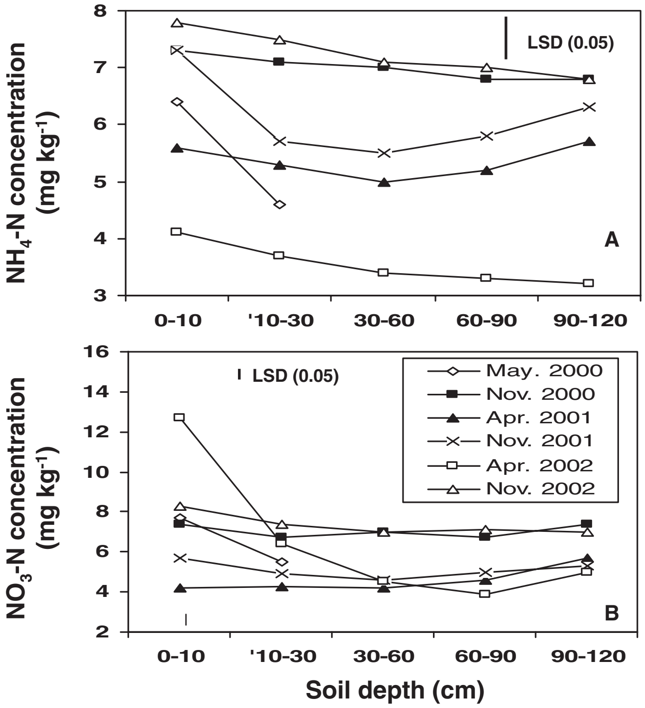

Fig. 1. Distribution of (A) NH_4–N and (B) NO_3–N concentrations in the soil profile at the 0- to 120-cm depth averaged across tillage, cover crops, and N fertilization rates from May 2000 to November 2002 in Fort Valley, GA. LSD (0.05) is the least significant difference between sampling dates at a soil depth at $P = 0.05$.

below 60 cm may have resulted either from ammonification exceeding nitrification as a result of higher soil water content than overlying layers or from greater cation exchange capacity of clay that favors NH_4–N retention.

The variations in NH_4–N concentration at 0 to 120 cm with date of sampling (Fig. 1A) could have resulted from differences in the amount of N returned to the soil from cover crop, cotton, and sorghum residues, N fertilization rates, and the temperature and rainfall between sampling dates that resulted in different N mineralization rates. The higher NH_4–N concentration in November than in April to May of each year was probably due to N fertilization to cotton and sorghum in the summer, followed by cover crop N returned to the soil in April, part of which was fixed from the atmosphere (such as in vetch) and part recycled from the soil (such as in rye and vetch). The NH_4–N concentration increases following cover crop incorporation into the soil due to mineralization (McKenney et al., 1995). Similarly, higher NH_4–N concentration in November 2000 and 2002 than in November 2001 may be attributed to higher amount of cover crop N in 2000 and 2002 than in 2001 (Table 1). The lower NH_4–N concentration in April 2002 than in other sampling dates may be either related to lower crop residue N returned to the soil in 2001 than in 2000 (Tables 1 and 4) or to increased nitrification of NH_4–N to NO_3–N (Fig. 1B) due to increased temperature from January to April in 2002 than in 2000, 2001, and the 41-yr average (Table 3). Another possible reason is that below-average precipitation from August 2001 to March 2002 (Table 3) reduced mineralization of soil organic N to NH_4–N, thereby reducing NH_4–N level while increasing NO_3–N level in April 2002 (Fig. 1B) due to its reduced leaching loss. Although NH_4–N concentrations varied between sampling dates, NH_4–N levels as high as NO_3–N levels throughout the sampling period could have partly resulted from air drying of soil samples, as air-drying of soil may increase NH_4–N concentration (Mulvaney, 1996).

Treatments also interacted significantly with soil sampling dates for NH_4–N content. The N fertilization × sampling date and tillage × N fertilization × sampling date interactions were significant ($P \leq 0.05$) for NH_4–N content at 0 to 10 cm and cover crop × N fertilization interaction was significant at 10 to 30 cm. The NH_4–N content at 0 to 10 cm, averaged across cover crops, was higher with 120 to 130 than with 0 kg N ha^{-1} in NT, ST, and CT in May 2000 and in NT in November 2001 (Table 5). The NH_4–N content at 10 to 30 cm, averaged across tillage and sampling dates, was higher with 120 to 130 than with 0 and 60 to 65 kg N ha^{-1} in the vetch treatment (Table 6). Similarly, NH_4–N content was

Table 4. Nitrogen uptake by cotton lint containing seed, sorghum grain, and their biomass (stems + leaves) as influenced by cover crops and N fertilization from 2000 to 2002 in Fort Valley, GA.

	N uptake					
	Cotton lint or sorghum grain†			Cotton and sorghum biomass†		
Treatment	2000	2001	2002	2000	2001	2002
	kg N ha^{-1}					
	Cover crop‡					
Rye	15a§	32b	16a	130b	81c	77b
Vetch	11b	60a	13a	220a	175a	98a
Vetch + rye	12b	58a	14a	190a	138b	101a
Weeds	11b	43ab	16a	124b	132b	74b
	N fertilization rate					
0	12a	41b	17a	204b	108b	80b
60–65	13a	46b	16a	269a	135a	86ab
120–130	11a	53a	11b	316a	152a	97a

† Cotton was grown in 2000 and 2002 and sorghum in 2001.
‡ Cover crops are rye, cereal rye; vetch, hairy vetch; vetch + rye, hairy vetch and rye biculture; and weeds, winter weeds or no cover crop.
§ Numbers followed by different letter within a column of a set are significantly different at $P \leq 0.05$ by the least square means test.

Table 5. Effects of tillage and N fertilization rates on soil NH_4–N content at the 0- to 10-cm depth averaged across cover crops from May 2000 to November 2002 in Fort Valley, GA.

		2000		2001		2002	
Tillage†	N fertilization	May	Nov.	Apr.	Nov.	Apr.	Nov.
	kg N ha^{-1}	kg NH_4–N ha^{-1}					
NT	0	7.0	9.8	7.5	7.5	6.1	11.2
	60–65	10.5	9.3	7.2	6.7	8.9	11.1
	120–130	13.4	9.6	7.1	13.4	6.4	10.7
ST	0	6.7	11.4	8.2	8.5	6.7	11.4
	60–65	9.2	10.5	8.5	8.8	6.2	11.6
	120–130	12.1	11.2	8.8	8.6	7.3	12.8
CT	0	5.2	10.5	7.2	8.4	5.3	10.2
	60–65	8.6	10.3	7.8	9.7	4.9	11.7
	120–130	10.4	10.9	8.2	5.8	5.7	11.6
LSD (0.05) for comparison among columns and rows = 4.6							
Means							
	0	6.3	10.6	7.6	8.1	6.0	11.0
	60–65	9.4	10.1	7.8	8.4	6.7	11.5
	120–130	12.0	10.6	8.1	9.3	6.5	11.7
LSD (0.05) for comparison among columns and rows = 2.5							

† CT, chisel till; NT, no-till; and ST, strip till.

Table 6. Effects of cover crops, N fertilization rates, and tillage on soil NH_4–N and NO_3–N contents at 0- to 10- and 10- to 30-cm depths averaged across soil sampling dates in Fort Valley, GA.

		Cover crop†			
Soil depth	Treatment	Rye	Vetch	Vetch + rye	Weeds
cm		kg NH_4–N ha^{-1}			
	N fertilization (kg N ha^{-1})				
10–30	0	16.2	16.7	16.5	16.6
	60–65	17.0	17.9	18.0	16.5
	120–130	16.8	21.4	17.7	16.5
LSD (0.05) for comparison among columns and rows = 3.4					
0–10	Tillage‡	kg NO_3–N ha^{-1}			
	NT	9.1	14.1	11.2	10.5
	ST	11.4	12.8	14.3	10.2
	CT	10.5	14.8	12.1	9.5
LSD (0.05) for comparison among columns and rows = 2.3					

† Cover crops are rye, cereal rye; vetch, hairy vetch; vetch + rye, hairy vetch and rye biculture; and weeds, winter weeds or no cover crop.
‡ CT, chisel till; NT, no-till; and ST, strip till.

higher with vetch than with other cover crops in the 120 to 130 kg N ha^{-1} treatment.

Nitrogen fertilization at 120 to 130 kg N ha^{-1} increased NH_4–N content at the surface soil compared with other N rates, regardless of tillage, in May 2000 and in NT in November 2001 (Table 5). Higher NH_4–N content with increasing N rate in May 2000 was due to soil sampling immediately after N fertilization. In contrast, higher NH_4–N content with high N rate in NT in November 2001 was probably due to reduced nitrification, as N fertilizer was surface-applied. With increased N addition from vetch compared with rye and weeds (Table 1), the 120 to 130 kg N ha^{-1} increased NH_4–N content at the subsurface soil compared with other N rates in the vetch treatment (Table 6). At the surface soil, such increase was not observed, probably because vetch residue mineralizes rapidly when incorporated into the soil to a greater depth. The vetch + rye maintained NH_4–N levels between vetch and rye in all N rates, except in the 60 to 65 kg N ha^{-1} treatment.

Soil Nitrate–Nitrogen

Similar to NH_4–N concentration, depth × sampling date and cover crop × depth × sampling date interactions were significant ($P \leq 0.05$) for soil NO_3–N concentration. Except for the May 2000 sample at 0 to 30 cm and the April 2002 sample at 0 to 90 cm, NO_3–N concentration, averaged across treatments, either remained at the same level or slightly increased from surface to subsurface soil layers (Fig. 1B). The NO_3–N concentration at 0 to 120 cm was higher in November 2000 and 2002 than in other sampling dates, except for the May 2000 sample at 0 to 10 cm and the April 2002 sample at 0 to 30 cm. The NO_3–N concentration, averaged across tillage and N fertilization rates, was higher with vetch than with rye and weeds at 0 to 30 cm in May 2000 (Fig. 2A), at 60 to 120 cm in April 2001 (Fig. 2C), and at 0 to 10 and 60 to 120 cm in November 2001 (Fig. 2D). Similarly, NO_3–N concentration was higher with vetch than with weeds at 0 to 30 cm and higher with vetch than with rye and vetch + rye at 90 to 120 cm in April 2002 (Fig. 2E). The NO_3–N concentration with vetch + rye was between vetch and rye for most soil depths and sampling dates.

As with NH_4–N concentration, variations in NO_3–N concentrations with soil depths and sampling dates was likely related to differences in N supplied by cover crops, N fertilization rates, N removal by cotton and sorghum, and seasonal variations in temperature and rainfall. Higher NO_3–N concentration with vetch than with rye and weeds in the surface and subsurface layers (Fig. 2) may be attributed to increased N supply (Table 1). Because of higher N concentration and lower C/N ratio, vetch decomposes rapidly in the soil and enriches soil mineral N more than rye (Kuo et al., 1997; Sainju et al., 1998). Although vetch + rye biculture supplied N similar to or greater than vetch, rye in the biculture appeared to immobilize part of soil NO_3–N, thereby resulting in NO_3–N concentration with vetch + rye that between vetch and rye. The lower NO_3–N concentration in the biculture, however, did not reduce N uptake by cotton and sorghum compared with vetch in 2 out of 3 yr (Table 4). Because of increased NO_3–N concentration with soil depth, vetch may increase the potential for N leaching compared with other cover crops.

The lower NO_3–N concentration at 0 to 120 cm in April and November 2001 than in other sampling dates (Fig. 1B) could be due to reduced N supplied by cover crops in 2001 compared with 2000 and 2002 (Table 1). In contrast, higher NO_3–N concentration at 0 to 10 cm in April 2002 than in other sampling dates was likely a result of increased nitrification of NH_4–N to NO_3–N at the surface soil due to above-average temperature from January to April 2002, followed by reduced potential for N leaching due to below-average precipitation from August 2001 to March 2002 (Table 3), as stated above.

The tillage × cover crop, cover crop × N fertilization, tillage × sampling date, and cover crop × sampling date interactions were also significant ($P \leq 0.05$) for soil NO_3–N contents at various depths. At 0 to 10 cm, NO_3–N content, averaged across tillage and N fertilization rates, was higher with vetch than with other cover crops in May 2000; higher with vetch, vetch + rye, and rye than with weeds in April 2002; and higher with vetch than with weeds in November 2002 (Table 2). At 0 to 120 cm, NO_3–N content was higher with vetch than with rye and weeds from April 2001 to April 2002, and higher with vetch than with weeds in November 2002. As with NO_3–N concentration, NO_3–N content with vetch + rye was between vetch and rye for most sampling dates.

From November 2000 to April 2001, NO_3–N content at 0 to 10 cm was reduced by 46 to 49% with vetch, vetch + rye, and weeds but only 38% with rye (Table 2). At 0 to 120 cm, 34 to 38% of NO_3–N was reduced with rye, vetch + rye, and weeds but only 21% with vetch during the same period. In contrast, from November 2001 to April 2002, NO_3–N content at 0 to 10 cm increased by 110% with weeds to 203% with vetch + rye. At 0 to 120 cm, NO_3–N content increased by 2% with rye to 17% with vetch + rye.

The differences in the reduction of NO_3–N levels with cover crops between the two winter seasons (from November 2000 to April 2001, and from November 2001

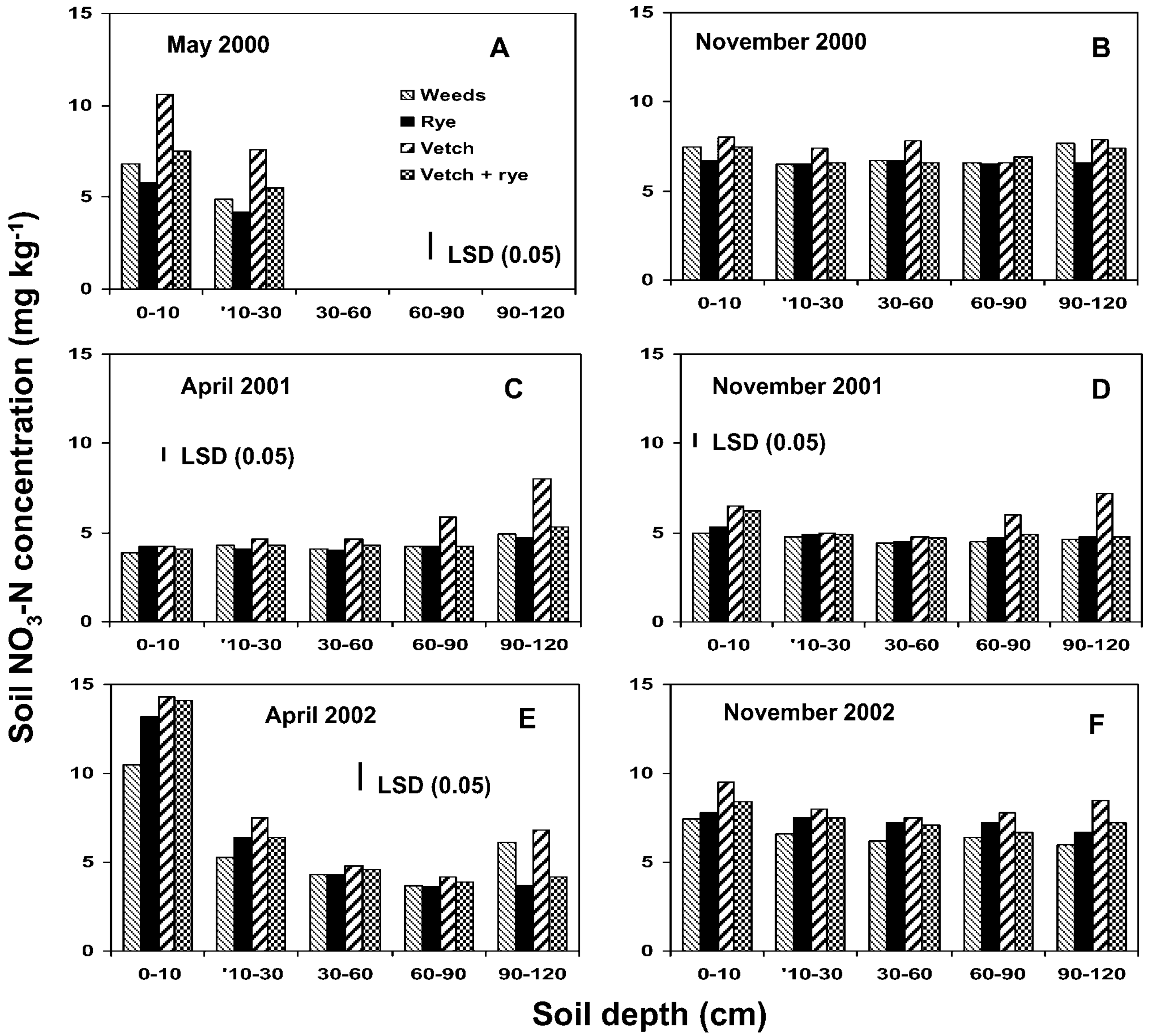

Fig. 2. Effect of cover crops on soil NO_3–N concentrations at the 0- to 120-cm depth averaged across tillage and N fertilization rates from May 2000 to November 2002 (A–F) in Fort Valley, GA. Rye denotes cereal rye; vetch, hairy vetch; vetch + rye, hairy vetch and rye biculture; weeds, winter weeds or no cover crop. LSD (0.05) is the least significant difference between cover crops at a soil depth at P = 0.05. No soil samples were collected from the 30- to 120-cm depth in May 2000.

to April 2002) could be explained by the differences in temperature and rainfall between the seasons. Total rainfall from November to April was 128 mm higher in 2000 to 2001 than in 2001 to 2002 but the mean monthly temperature from November to April was 1.6 to 7.6°C higher in 2001 to 2002 than in 2000 to 2001 (Table 3). Greater rainfall could have increased NO_3–N loss mostly by leaching, thereby reducing the NO_3–N level from November 2000 to April 2001. Some of this loss also may have occurred from denitrification, since clay content increased to 350 g kg^{-1} below 30 cm. In contrast, increased nitrification of NH_4–N to NO_3–N due to higher temperature, followed by reduced leaching loss due to below-average precipitation could have increased NO_3–N level from November 2001 to April 2002.

Nitrogen loss during the periods from November 2000 to April 2001 and from November 2001 to April 2002 as influenced by cover crops can be better revealed by determining total N levels in soil at the 0- to 120-cm depth and in cover crop, cotton, and sorghum residues in November and April, 2000 to 2002 (Table 7). Total soil and crop residue N were higher with vetch and vetch + rye than with weeds in November 2000 and April 2001 and higher than with rye and weeds in November 2001 and April 2002. The amount of N loss from soil and crop residue was higher with vetch than with other cover crops during November 2000 to April 2001. In contrast, the amount of N loss was similar between cover crops during November 2001 to April 2002. The vetch and rye biculture lost the lowest amount of N. The N loss during these periods can be mostly accounted for by loss due to leaching because of reduced evapotranspiration and N uptake by crops and precipitation exceeding water holding capacity of the soil (Meisinger et al., 1991). Because

Table 7. Effect of cover crops on N loss from crop residue and soil (NH_4–N + NO_3–N + organic N contents) at 0- to 120-cm depth from November 2000 to April 2001 and from November 2001 to April 2002 in Fort Valley, GA.

	Total crop residue and soil N‡			Total crop residue and soil N§		
Cover crop†	Nov. 2000	Apr. 2001	Loss	Nov. 2001	Apr. 2002	Loss
	kg N ha^{-1}					
Rye	5057bc¶	4888b	169b	4820b	4764b	56a
Vetch	5455a	5235a	220a	5323a	5244a	79a
Vetch + rye	5249ab	5141a	108c	5222a	5182a	40a
Weeds	4869c	4709b	160b	4725b	4649b	76a

† Cover crops are rye, cereal rye; vetch, hairy vetch; vetch + rye, hairy vetch and rye biculture; and weeds, winter weeds or no cover crop.
‡ Include soil NH_4–N + NO_3–N + organic N contents at the 0 to 120 cm and N returned to the soil from cotton biomass (stems + leaves) in November 2000 or cover crop biomass in April 2001.
§ Include soil NH_4–N + NO_3–N + organic N contents at the 0 to 120 cm and N returned to the soil from sorghum biomass (stems + leaves) in November 2001 or cover crop biomass in April 2002.
¶ Numbers followed by different letter within a column are significantly different at $P \leq 0.05$ by the least square means test.

of the increased N loss, the potential for N leaching remains higher with vetch than with other cover crops. Several researchers (McCracken et al., 1994; Vyn et al., 1999; Bergstrom and Kirchmann, 2004) reported that NO_3–N leaching loss was higher with legume than with nonlegume cover crops. The loss from the vetch treatment can be minimized by mixing vetch with rye.

Averaged across cover crops and N fertilization, NO_3–N content at 10 to 30 cm was higher in ST and CT than in NT in May 2000, higher in NT than in ST and CT in April 2001, and higher in NT and ST than in CT in April 2002 (Table 2). The NO_3–N content at 0 to 10 cm was not significant for tillage × sampling date interaction. From November 2000 to April 2001, NO_3–N content at 10 to 30 cm was reduced by 37 to 40% in ST and CT but was increased by 11% in NT. From November 2001 to April 2002, NO_3–N content was increased by 1% in CT to 69% in ST.

The higher NO_3–N content in ST and CT than in NT in May 2000 probably resulted from organic N mineralization due to soil disturbance from tillage, since soil sample was taken after tillage and N fertilization in this sampling date. In contrast, higher NO_3–N content in NT and ST than in CT in April 2001 and 2002 likely resulted from reduced NO_3–N loss due to reduced tillage, since NO_3–N loss from November 2000 to April 2001 and from November 2001 to April 2002 was lower in NT than in ST and CT (Table 2).

The NO_3–N content at 0 to 10 cm, averaged across N fertilization rates and sampling dates, was higher in ST than in NT in rye and vetch + rye treatments (Table 6). The NO_3–N content was higher with vetch than with other cover crops in NT and CT but was higher with vetch + rye than with rye and weeds in ST. Incorporation of residue due to tillage likely increased NO_3–N content at the surface soil with rye and vetch + rye in ST and CT compared with NT. At 30 to 60 cm, NO_3–N content, averaged across tillage and sampling dates, was higher with vetch than with weeds in the 0 kg N ha^{-1} treatment (Fig. 3A) and higher with vetch than with other cover crops in the 120 to 130 kg N ha^{-1} treatment

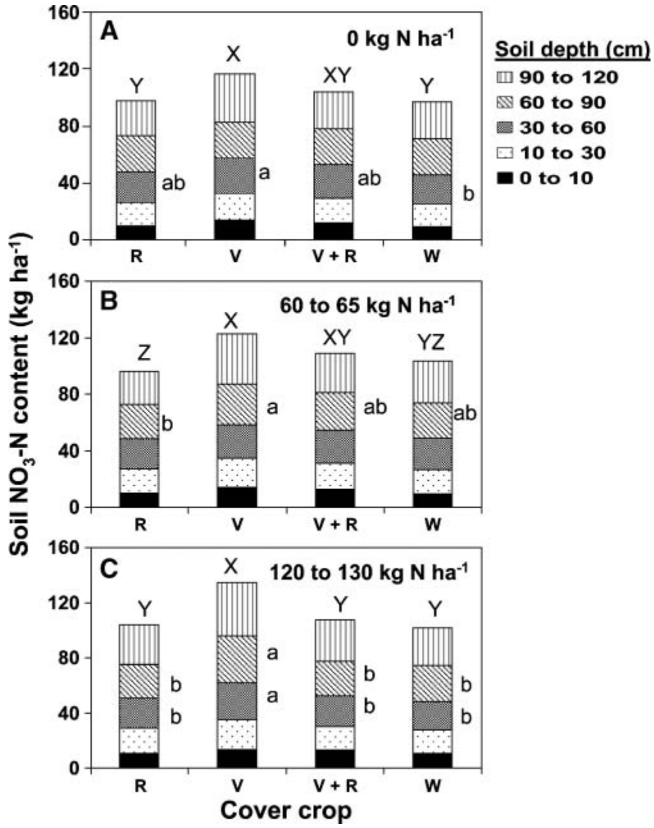

Fig. 3. Effect of cover crops on soil NO_3–N contents at the 0- to 120-cm depth in (A) 0 kg N ha^{-1}, (B) 60 to 65 kg N ha^{-1}, and (C) 120 to 130 kg N ha^{-1} averaged across tillage and soil sampling dates in Fort Valley, GA. R, denotes cereal rye; V, hairy vetch; V + R, hairy vetch and rye biculture; W, winter weeds or no cover crop. Bars followed by different lowercase letter within a soil depth are significantly different at $P \leq 0.05$ by the least square means test. Bars followed by different uppercase letter at the top are significantly different at $P \leq 0.05$ by the least square means test.

(Fig. 3C). At 60 to 90 cm, NO_3–N content was higher with vetch than with rye in the 60 to 65 kg N ha^{-1} treatment (Fig. 3B) and higher with vetch than with other cover crops in the 120 to 130 kg N ha^{-1} treatment (Fig. 3C). At 0 to 120 cm, NO_3–N content was higher with vetch than with rye and weeds in all the N rate treatments (Fig. 3A, 3B, and 3C). Averaged across tillage, N fertilization, and sampling dates, NO_3–N content was higher with vetch than with rye and weeds at all depth ranges from 0 to 120 cm (Fig. 4A). Averaged across tillage, cover crops, and sampling dates, NO_3–N content was higher with 120 to 130 than with 0 kg N ha^{-1} at 10 to 30, 60 to 120, and 0 to 120 cm (Fig. 4B).

Because of higher NO_3–N concentration, vetch increased NO_3–N content at various soil depths compared with rye and weeds (Table 6, Fig. 3 and 4A). Rye did not significantly reduce NO_3–N content compared with weeds. The vetch + rye treatment consistently maintained NO_3–N level between vetch and rye, regardless of tillage, N rates, and sampling dates. Similarly, because of higher N availability, the 120 kg N ha^{-1} increased NO_3–N content in the subsoil layers compared with 0 kg N ha^{-1} (Fig. 4B). Although vetch alone increased NO_3–N content, increased N contribution both from

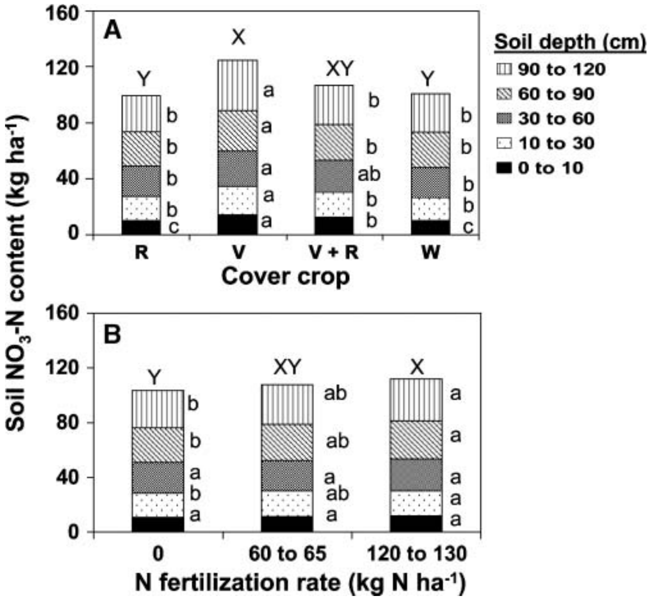

Fig. 4. Effect of (A) cover crops and (B) N fertilization rates on soil NO_3–N contents at the 0- to 120-cm depth averaged across tillage and soil sampling dates in Fort Valley, GA. R, denotes cereal rye; V, hairy vetch; V + R, hairy vetch and rye biculture; W, winter weeds or no cover crop. Bars followed by different lowercase letter within a soil depth are significantly different at $P \leq 0.05$ by the least square means test. Bars followed by different uppercase letter at the top are significantly different at $P \leq 0.05$ by the least square means test.

vetch and 120 to 130 kg N ha^{-1} further increased NO_3–N content in the subsoil layers (Fig. 3 and 4), indicating possible movement of NO_3–N down the soil profile with percolating water (Liang and McKenzie, 1994; Sainju et al., 1999; Zhu and Fox, 2003; Al-Kaisi and Licht, 2004). Since ST and CT with vetch or vetch with 120 to 130 kg N ha^{-1} increased soil NO_3–N accumulation and N loss in the winter was higher with vetch than with rye and weeds, conservation tillage, such as NT, with vetch + rye biculture and 60 to 65 kg N ha^{-1} could optimize soil N availability to crops and reduce the potential for N leaching.

Cotton and Sorghum Nitrogen Uptake

Nitrogen uptake by cotton and sorghum from 2000 to 2002 was significantly ($P \leq 0.05$) influenced by cover crops and N fertilization rates but not by tillage. Nitrogen uptake by cotton lint in 2000 was higher with rye than with other cover crops (Table 4). Similarly, N uptake by cotton lint in 2002 was higher with 0 and 60 than with 120 kg N ha^{-1}. In contrast, N uptake by sorghum grain in 2001 was higher with vetch and vetch + rye than with rye and higher with 130 than with 0 and 65 kg N ha^{-1}. Nitrogen uptake by cotton biomass (stems + leaves) in 2000 and 2002 was higher with vetch and vetch + rye than with rye and weeds and higher with 120 than with 0 kg N ha^{-1}. Similarly, N uptake by sorghum biomass in 2001 was higher with vetch than with other cover crops and higher with N fertilization than without.

The higher N uptake by cotton lint with rye than with vetch and vetch + rye or higher with 0 and 60 than with 120 kg N ha^{-1} suggests that increased soil mineral N content with legume cover crop or higher rate of N fertilization is probably detrimental for cotton lint production. In contrast, higher N uptake by cotton biomass with vetch and vetch + rye than with rye and weeds or higher uptake with N rates than without indicates that increased soil mineral N from hairy vetch and N fertilization increased stem and leaf growth at the expense of lint yield. Boquet et al. (2004) observed that cotton lint N uptake increased with increased N fertilization rates from 0 to 118 kg N ha^{-1} with wheat cover crop or native cover but decreased with hairy vetch. The tolerance of cotton lint N uptake following rye to high N rates was probably related to N immobilization caused by higher C/N ratio of rye residue (Dabney et al., 2001). It may also be possible that some unidentified factors retard cotton's vegetative growth in rye residue (Hicks et al., 1989). High N can produce excessive vegetative growth that delays maturity and harvest and reduces cotton lint yield and N uptake (Hutchinson et al., 1995; Howard et al., 2001). In contrast to cotton lint, increased sorghum grain and biomass N uptake with vetch and vetch + rye compared with rye or with increasing rates of N fertilization suggests that both sorghum grain and stalk respond positively to N application. Increase in sorghum grain and biomass N uptake with legume cover crops and N fertilization compared with nonlegume or no cover crop and N fertilization were reported by several researchers (Hargrove, 1986; McVay et al., 1989; Sweeney and Moyer, 2004). Reduced N uptake by cotton lint with vetch and vetch + rye compared with rye or weeds or with 120 compared with 0 and 60 kg N ha^{-1} suggests that N supplied by vetch may have been excessive and that the N fertilization rate recommended for cotton can be reduced by half to sustain cotton yield while reducing the cost of N fertilization. Similar levels of N uptake by cotton lint, sorghum grain, and cotton and sorghum biomass with vetch and vetch + rye suggests that vetch can be replaced by vetch + rye to sustain cotton and sorghum N uptake. Since tillage did not influence cotton and sorghum N uptake, NT with vetch + rye and 60 to 65 kg N ha^{-1} may be used to optimize crop N take and reduce the potential for soil erosion compared with ST and CT with or without cover crops and with 120–130 kg N ha^{-1}.

CONCLUSIONS

Variations in N supplied by cover crops and N fertilization rates influenced soil mineral N content at the 0- to 10-cm depth due to tillage and at 0 to 120 cm, regardless of tillage. The NT with 120 to 130 kg N ha^{-1} increased NH_4–N content and ST with vetch + rye increased NO_3–N content at the surface soil. Increased N supplied by vetch and 120 to 130 kg N ha^{-1} increased NO_3–N contents compared with other cover crops and N rates at the surface and subsurface soil layers. The NH_4–N concentration was lower at 30 to 60 cm than at overlying or underlying layers but the concentration at 0 to 120 cm was higher at harvest than at planting due to N supplied by cover crops and N fertilization to cotton and sorghum. Similarly, NO_3–N concentration was higher with vetch than with other cover crops at most soil depths and sampling dates. Nitrogen loss from crop residue and soil at 0 to 120 cm in the winter was higher with vetch than with rye and weeds. Although rye increased N uptake by cotton lint, vetch increased N uptake by sorghum grain and cotton and sorghum biomass. Vetch may reduce the rate of N fertilization and sustain cotton and sorghum N uptake but also poses a greater risk of N leaching from the soil profile due to increased accumulation of NO_3–N. Because of similar N supplying capacity and N uptake by succeeding crop as vetch and soil NO_3–N accumulation between vetch and rye, vetch + rye biculture may sustain cotton and sorghum N uptake and reduce the risk of N leaching compared with vetch monoculture, regardless of tillage and N fertilization. Conservation tillage, such as NT, with hairy vetch + rye cover crop and 60 to 65 kg N ha^{-1} may not only optimize soil mineral N and cotton and sorghum N uptake but also reduce the cost of N fertilization and potentials for soil erosion and N leaching compared with conventional tillage, such as CT, with or without cover cropping and 120 to 130 kg N ha^{-1}.

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